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The Radial Displacement of the HPT Blade under the Effects of the Temperature Field and the Centrifugal

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Abstract

The blade temperature field is computed using the finite element software of ANSYS and Hypermesh. The radial displacement response under the temperature field and centrifugal is analyzed. And a new method of plotting the grid and loading the boundary for complicated three-dimensional model in the finite element software is advanced. The heat transfer coefficients at different parts of the blade are introduced. The results show that for the temperature circumference distribution of the blade profile, the temperature is the highest at the leading and trailing edges and low at the middle. For the radial distribution the temperature is low at the blade root, and high at the blade profile and the integral tip shroud. The effect of temperature field is the main reason of the blade radial displacement while the centrifugal effect accounts for little.

Keywords: blade; temperature; displacement;centrifugal;finite element analysis

1. Introduction

The environments of the high temperature parts on gas turbine have deteriorated seriously as the gas temperature becomes higher and higher. According to the statistics made by the authoritative departments of USA, more than 60% of the gas turbine faults are on the high temperature parts, and the ratio is increasing [1]. Except the limitations of the materials and the technics, the main reason is that it is hard to predict the heat states of the high temperature parts accurately. It is known that it will decrease half of the parts life when the temperature increases 15K on high temperature1. So it is necessary to make great efforts to improve the analysis precision of the heat states of the high temperature.

The within-hole and near-hole physics in relation to heat transfer on a film-cooled blade were studied in [2]. Film-cooling effectiveness and the heat transfer coefficient on the blade, hub and shroud for a rotating high-pressure turbine blade were computed in [3]. The film-cooling effectiveness distributions on the blade tip were measured and Numerical predictions were performed using Fluent in [4]. The effect of

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relative blade position on heat transfer in a stationary blade and shroud was investigated in [5]. Numerical simulations were performed to predict the film cooling effectiveness and the associated heat transfer coefficient in a 1-1/2 turbine stage in [6].

Besides, analyzing the temperature fields of the blade and computing the radial elongations of the blade under the effects of the temperature fields and centrifugal are important aspects of the study of tip clearance control of the gas turbine.

A simple model to compute the blade tip clearance was founded in [7]. The mode was improved in [8]. The high pressure turbine tip clearance variation versus time was analyzed by the finite element method, and the boundary conditions about the temperature and pressure were loaded by means of the segmental application method in [9]. The thermal-structure coupled displacement of the case, disk & blade and the transient response of tip clearance in temperature and rotor speed were analyzed in [10]. A new method to apply thermal loads to the disk was given in [11].

In the paper the blade temperature field is computed using the finite element software of ANSYS and Hypermesh. The radial displacement response under the temperature field and centrifugal is analyzed by the thermal-structure coupled analysis. And the problem of plotting the grid and loading the boundary for complicated three-dimensional model is solved.

2. The model

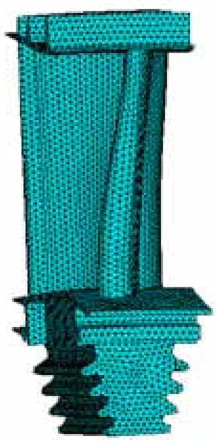

Fig.1 three-dimensional model of the HPT blade

Three-dimensional model of the blade of high pressure turbine with integral tip shroud is found using UG software in the paper, as shown in figure 1. It is not convenient to plot grid and load the thermal boundary for the complicated three-dimensional model and some areas will be lost if it is imported into ANSYS software directly, and it is not accurate to plot the grid automatically while it is too cockamamie to plot manually in ANSYS. To solve these problems, we import the model into Hypermesh software to plot grid and establish some area components in it first, and then import the model into ANSYS from Hypermesh. The boundary is loaded in ANSYS. The purpose to establish the area components is to load the thermal boundary conveniently in ANSYS. Thus the problem that the thermal boundary couldn't be loaded when importing the model from Hypermesh into ANSYS is solved.

In the paper, the thermal-structure coupled analysis is used. The temperature boundary of the structure analysis is loaded by importing the results of the thermal analysis. The thermal convection is considered while he thermal radiation is ignored.

3. The boundary

3.1 the thermal boundary

The third kind thermal boundary is used. As the blade structure is complicated, the thermal boundary is different at different parts and the heat transfer coefficient varies as the temperature changes. So it is necessary to compute the heat transfer coefficient respectively.

1）The heat transfer coefficient formula of the blade surface

In the formulas, the cascade geometry is considered sometimes except the Reynolds number. One representative formula of them is [12]

$$N_{u_{av}} = \left(\frac{0.0805}{k^{2.85}} - 0.0022 \right) R_e^{0.74k^{0.34}} P_r^{1/} \tag{1}$$

where $k = \sin\beta_2 / \sin\beta_1$ *. The range of the formula is* $2\times10^4 \le R_e \le 7\times10^5$ *,* $0.4 \le k \le 1.4$.

For the cascade of which the degree of reaction is more than 0.3,the partial heat transfer coefficients are in the range below [12]:

The average heat transfer coefficient of pressure side

$$h_{p,av} = (1 \sim 1.15)\, h_{av} \tag{2}$$

the average heat transfer coefficient of suction side:

from the leading edge secant point to (0.6～0.7)suction side length,

$$h_{sa,av} = (0.75 \sim 0.85)\, h_{av} \tag{3}$$

the other part of the suction side,

$$h_{sb,av} = (1.2 \sim 1.4)\, h_{av} \tag{4}$$

the heat transfer coefficient of the leading edge stop point

$$h_{\mathrm{f}} = \lambda_1 Re_1^{0.5} / d_{\mathrm{f}} \tag{5}$$

the average heat transfer coefficient of the leading edge

$$h_{\mathrm{f,av}} = 0.635\, \lambda_1 Re_1^{0.5} / d_{\mathrm{f}} \tag{6}$$

the trailing edge with gap:

pressure side (0.15 pressure side length)

$$h_{rp,av} = 0.057\, \lambda_2 Re_{2b}^{0.7} / d_r \tag{7}$$

suction side (0.15 suction side length)

$$h_{rs,av} = 0.051 \lambda_2 Re_{2b}^{0.73} / d_r \tag{8}$$

2）The heat transfer coefficient at the integral tip shroud

The heat transfer compute at the teeth can use the heat transfer coefficient formula of the sealing teeth below.

$$Nu_{av} = 0.307 Re_p^{0.74} \left(S/B\right)^{0.5} \tag{9}$$

In the equation (9), $l_0 = 2B$ .The range of the formula is $Re_p = \left(0.6 \sim 2.2\right) \times 10^4$, $Rt = 0 \sim 4.41$.

3）The heat transfer coefficient at the blade root board

$$Nu_{av} = 0.065 Re_m^{0.8} S_r^{-0.54} \tag{10}$$

where $Re_m = \frac{1}{2}\left(Re_1 + Re_2\right)$, $Nu_{av} = hb/\lambda_2$, $Re_1 = \omega_1 b/\nu_1$, $Re_2 = \omega_2 b/\nu_2$.

4）The heat transfer coefficient of the cooling inside the blade

If the inside cooling passage shape is U with ribs, the heat transfer formula is[12]

radial exit flow parts

$$Nu_{av} = 0.3833 Re^{0.785} Rt^{*0.619} Bo^{*-0.266} \tag{13}$$

radial inlet flow parts

$$Nu_{av} = 0.01 Re^{0.87} Rt^{*0.25} Bo^{*-0.083} \tag{14}$$

The average Nu number of the total U-shape cooling passage is

$$Nu_{av} = 0.021 Re^{0.822} Rt^{*0.39} Bo^{*-0.158} \tag{15}$$

where $Rt^* = 1 + 100 Rt$, $Rt = \omega d/\nu_0$, $Bo^* = \left(\frac{T_{w,av} - T_0}{T_{w,av}}\right) Rt^{*2} \left(\frac{r_0}{d}\right)$.

5) The disposal of the touching resistance between the blade rabbet and the mortise

The touching resistance R_c can't be loaded on the model directly if it is not disposed equivalently. The equation is

$$h = 1/R_c \tag{16}$$

There is a equation for the touching resistance between the blade rabbet and the mortise

$$\frac{\sigma}{R_c \times K} = 0.00027 \left(\frac{P}{H}\right)^{0.618} \tag{17}$$

The touching resistance can be computed by (17), and then be transformed into the heat transfer coefficient of the convection to load by (16).

3.2 the structure boundary

1) The displacement restriction

X,Y,Z directions displacement restrictions are loaded at the nodes of the blade rabbet which touch the mortise.

2) The centrifugal load steps

The angular velocity of 995rad/s rotating around the X axis is loaded at the all blade nodes which is corresponding to the rotate speed of 9500r/min.

4. Results and analysis

Applying the thermal-structure coupled analysis, the temperature boundary of the structure analysis is loaded by importing the results of the thermal analysis.

The figures 2 and 3 show that for the temperature circumference distribution of the blade profile, the temperature at the leading and trailing edges is the highest which reaches 920℃,and the temperature at the middle is low. For the radial distribution the temperature at the blade root is low, and it is high at the blade profile and the integral tip shroud. The heat transfers from the blade rabbet to the mortise. And there are cooling air inside the rabbet and gap blowing cool between the blade rabbet and the mortise. So the rabbet temperature is low. The reason why the leading edge temperature is high is that the heat transfer is sufficient there as the gas impinges the leading edge. The laminar flow change into overflow in the boundary layer after the breaking point and the heat transfer coefficient rises sharply, the heat transfers fully at the trailing edge and the temperature is high there. As there is almost no cooling air at the integral tip shroud, the temperature is high there. So it is necessary to enhance the cool of the leading and trailing edges and the integral tip shroud by means of the film-cooling and impingement cooling etc.

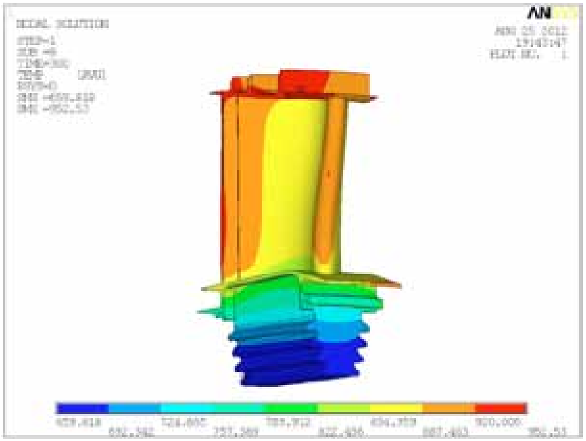

Fig.2 the blade temperature field at the pressure side

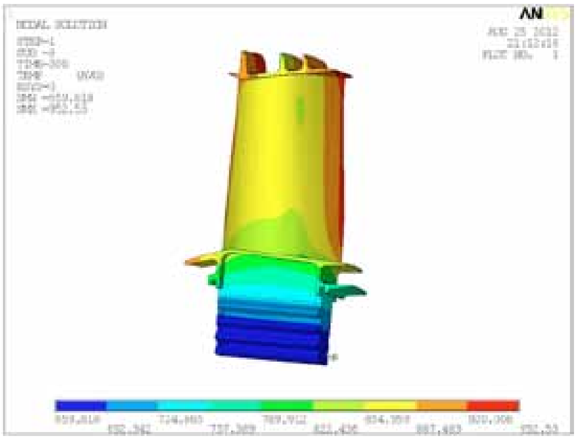

Fig.3 the blade temperature field at the suction side

The figure 4 shows the radial displacement of the integral tip shroud is the most which reaches to 1.3mm under the effect of the temperature field. The displacement at the blade root is little. One reason is that it expands greatly as temperature is high at the integral tip shroud while little as temperature is low at the root. Another is that the displacement at the blade rabbet is zero as it is restricted by the mortise while the displacement of the blade accumulates at the integral tip shroud.

The figure 5 shows that the displacement is great at the integral tip shroud under the effect of centrifugal which is more than 0.08mm and the most reaches to 0.244mm. The displacement at the blade root is little and the displacement at the blade rabbet is zero as it is restricted by the mortise. The displacement of the blade accumulates at the integral tip shroud and reaches the most.

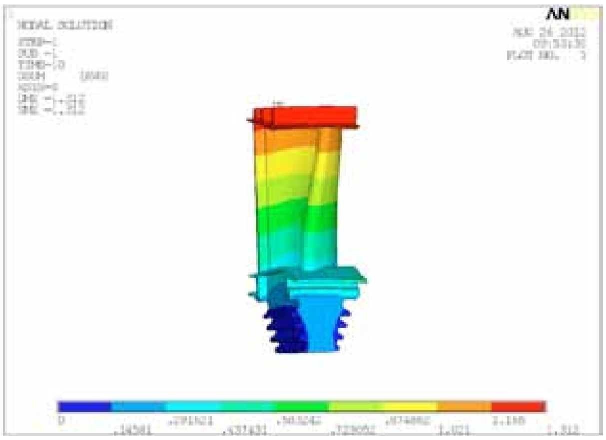

Fig. 4 the displacement under the effect of the temperature field

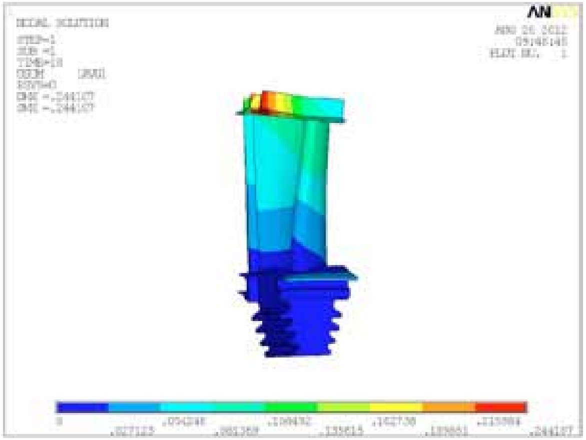

Fig. 5 the displacement under the effect of the centrifugal

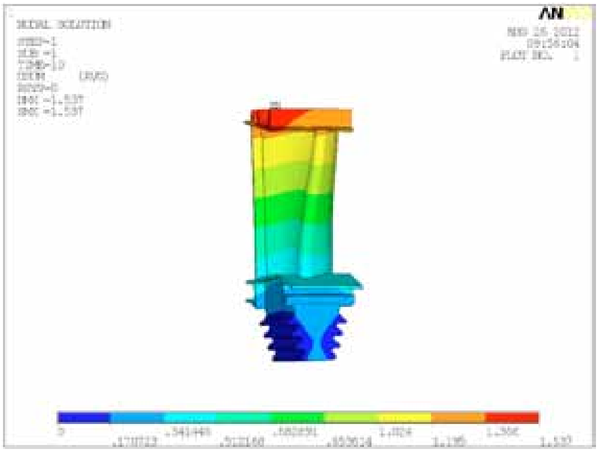

Fig. 6 displacement under the effects of the temperature field and centrifugal

From the figures 4～6 we know that the effect of temperature field is the main reason for the blade radial displacement while the centrifugal effect accounts for little. The maximal displacement under the centrifugal effect accounts for15.88% of the maximal total displacement of the blade.

5. Conclusions

In the paper the blade temperature field is computed using the finite element software of ANSYS and Hypermesh. The radial displacement response under the temperature and centrifugal is analyzed by the thermal-structure coupled analysis. The conclusions are as below:

It is a convenient method for finite element analysis to import the model into Hypermesh software to plot grid and establish some area components in it first, and then import the model into ANSYS from Hypermesh to load the boundary.

. For the temperature circumference distribution of the blade profile, the temperature is the highest at the leading and trailing edges and low at the middle. For the radial distribution the temperature is low at the blade root, and high at the blade profile and the integral tip shroud. It is necessary to enhance the cool of the leading and trailing edges and the integral tip shroud by means of the film-cooling and impingement cooling etc.

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